Acoustical Scattering, Propagation, and Attenuation Caused by Two Abundant Pacific Schooling Species: Humboldt Squid and Hake

Kelly J. Benoit-Bird
College of Oceanic and Atmospheric Sciences
104 Oceanography Admin Bldg
Oregon State University
Corvallis, OR 97331-5503
phone: (541) 737-2063 fax: (541) 737-2064 email: kbenoit@coas.oregonstate.edu

Joseph D. Warren
School of Marine and Atmospheric Sciences
Stony Brook University
Marine Sciences Research Center
Stony Brook - Southampton
239 Montauk Hwy
Southampton, NY 11968
phone: 631-632-5045 email: joe.warren@stonybrook.edu

Award #: N00014-11-1-0146

LONG-TERM GOALS

Our long-term goal is to predict the acoustic characteristics expected from aggregations of hake and jumbo squid off the west coast of North America within the frequency range of tactical, low to mid-frequency naval sonars.

OBJECTIVES

Our objectives are to:

- Measure the material properties of jumbo squid and hake
- Characterize the inhomogeneity of these properties and identify important scattering mechanisms
- Develop target strength models for both species as a function of frequency and depth
- Measure target strength of individuals of both species to validate models
- Measure in situ the spatial and temporal distributions of squid and hake
- Develop propagation, attenuation, and scattering models for these aggregations

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Acoustical Scattering, Propagation, and Attenuation Caused by Two Abundant Pacific Schooling Species: Humboldt Squid and Hake**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **College of Oceanic and Atmospheric Sciences Oregon State University 104 Ocean Admin Bldg Corvallis, OR 97331-5503**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

To accomplish our goal of predicting the in situ scattering, propagation, and attenuation from monospecific and mixed schools of squid and hake, we will combine information from field surveys of aggregations with measurements of the biological and physical habitat surrounding these aggregations to identify key parameters related to the distribution and behavior of these animals. These parameters will be used to create probability surfaces for aggregations of various types. These surfaces will be combined with the acoustic scattering models to predict the range of acoustic scattering expected from this biologically created acoustic uncertainty under given environmental conditions.

WORK COMPLETED

As part of an ONR supported cruise (26 July – 10 August, 2012), we collected physical samples and in situ data to be used in understanding and predicting the scattering, propagation, and attenuation from monospecific and mixed schools of squid and hake. Schooling fish can cause strong acoustic scattering and attenuation, dramatically altering the propagation of sound, particularly in coastal environments. Off the west coast of the United States, an area important for acoustical testing and tactical exercises, the most abundant species by biomass is Pacific hake, *Merluccius productus*, a fish with an air-filled swimbladder that averages 50 cm in length with maximum lengths of up to 90 cm. A more recent immigrant to these waters, is the similarly sized and highly abundant jumbo or Humboldt squid, *Dosidicus gigas*, which lacks any air-filled cavities. Before the invasion of Humboldt squid into the California current in the mid 1990's, aggregations of hake were shown to be the strongest biological sources of low frequency (e.g. hundreds of Hz to tens of kHz) acoustic scattering off the US West coast. Given the similarities observed in the scattering of individual hake and jumbo squid, it is highly likely that aggregations of squid show similarly strong scattering within the frequency band of tactical naval sonars.

During this field effort, we collected in situ data from aggregations of Pacific hake that ranged in length from 20 to 50 cm. These aggregations ranged from discrete schools to extensive layers sometimes nested within each other. These hake aggregations frequently overlapped with aggregations of other organisms including larval fish with large swimbladders, myctophids that make up the deep scattering layer, and Humboldt squid. We were able to measure aggregations under this full range of conditions at frequencies ranging from 10 kHz up to 200 kHz, including broadband measurements at tens of kHz.

As part of our in situ observations, we were able to make in measurements of target strength over the full frequency range used for a large number of individuals. These data have yet to be analyzed but will play a critical role in the evaluation of acoustic models we are developing.

In addition to in situ data, a large of number of samples of the species observed within our study area was obtained. In addition to being used for ground-truthing, the material properties (density contrast and sound speed) of more than 1500 individuals were measured. This large sample size combined with careful measures of swimbladder shape, reproductive condition, stomach fullness, and other independent variables will allow us to examine the effects of biological variability on acoustic characteristics of these animals. Finally, a number of these individual animals were preserved for characterization using CT scanning for detailed acoustical modeling.

The measurements and samples obtained are providing data on the material properties of animals, the variables that drive inhomogeneity of these properties, and helping us to identify important scattering mechanisms in soft-bodied animals. All of these data will be used to develop species and depth specific target strength models that will be validated against the data collected in situ. These individual models will be combined with field observations of the spatial and temporal distributions of squid and hake to create predictions of the acoustic characteristics expected from aggregations of hake and jumbo squid off the west coast of North America within the frequency range of tactical, low to mid-frequency naval sonars.

RESULTS

Both hake and Humboldt squid form aggregations at a range of individual densities including true schools where individuals are polarized and coordinated. Before the invasion of Humboldt squid into the California current in the mid 1990's, aggregations of hake were shown to be the strongest biological sources of low frequency (e.g. hundreds of Hz to tens of kHz) acoustic scattering off the US West coast Given the similarities in the scattering of individual hake and jumbo squid, it is highly likely that aggregations of squid show similarly strong scattering within the frequency band of tactical naval sonars. Preliminary measurements show that aggregations of Humboldt squid and hake can be found in close proximity to each other and even in mixed aggregations (Figure 1). It is not clear if this mixing will affect the multiple scattering from these aggregations and thus complicate predictions of scattering and propagation. The physical and acoustic characteristics of these species must be measured and modeled both alone and together to fully accomplish the goal of predicting the range, variability, and uncertainty from biologically-created acoustic scattering in the coastal North Pacific.

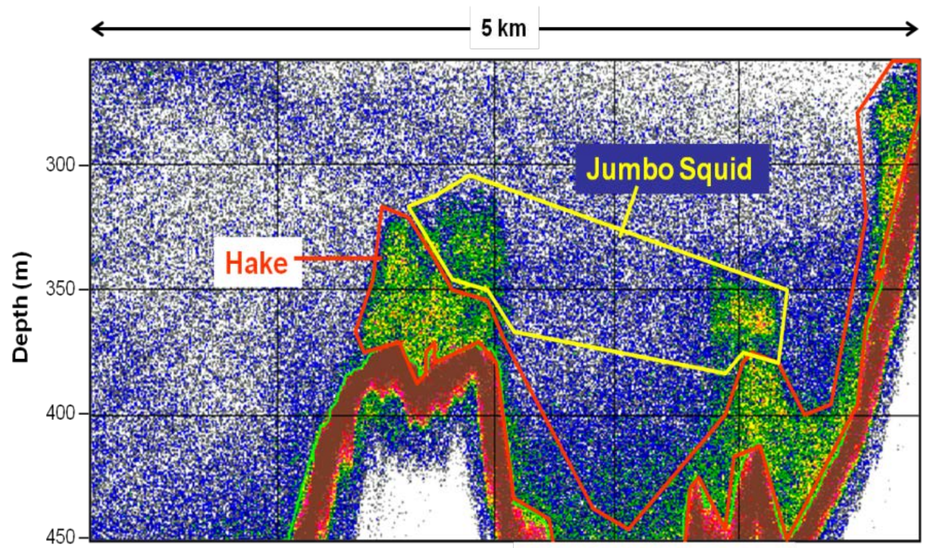

Figure 1. An echogram recorded at 38 kHz during NOAA's 2009 hake survey about 80 nmi south of the US-Canadian border. Large aggregations of hake and squid, confirmed by trawls equipped with a video camera, were found in close proximity to each other and showed broadly similar scattering strengths and characteristics despite their differences in morphology.

IMPACT/APPLICATION

The use of acoustics in coastal waters for sensing and detection requires understanding the natural sources of variance in propagation, attenuation, and scattering. Recent work has revealed that aggregations of fish and other biota are, in some cases, the largest sources of this variance. We will extend these studies to make quantitative predictions about scattering, propagation, and attenuation at low to mid frequencies from aggregations of two abundant, large species off the west coast of North America, an important navy tactical and training area. These species have remarkably different morphologies and internal characteristics, yet both show strong scattering over the same range of frequencies, presenting a unique opportunity to evaluate the mechanisms of scattering from individual animals as well as mono- and hetero-specific aggregations. The models, measurements, and predictions resulting from this work will be directly applicable to naval operations within the habitat of hake and squid and will extend our general understanding of biologically driven acoustic processes.

RELATED PROJECTS

This work is part of a Basic Research Challenge initiative of Fish Acoustics and is related to the other projects within this initiative. Most notably, some field work for this project will be conducted in conjunction with efforts by Gauss et al. and Diachok.

HONORS/AWARDS/PRIZES

2007 **Kavli Frontiers Fellow,** National Academy of Sciences
2008 **Ocean Sciences Early Career Award,** American Geophysical Union
2009 **R. Bruce Lindsay Award,** Acoustical Society of America
2010 **MacArthur Fellowship**, John D. and Catherine T. MacArthur Foundation
2011 **Ocean Sciences Meeting** Plenary Speaker
2012 **PopTech** Science Fellow
2012 **Oregon State University Promising Scholar**